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16. ABSTRACT Future trends in environmental monitoring and instrumentation will reflect the growing need to measure total exposure of critical receptors to specific pollutants. This paper describes the major monitoring objectives expected and the design criteria for developing and implementing monitoring systems to meet these objectives. It deals with requirements for air and water monitoring systems as well as those for integrated monitoring, biological monitoring, personnel exposure monitoring, and remote monitoring systems which will be needed in the immediate future. It describes the analytical laboratory support that will be required for measuring such pollutants as respiratory irritants, organic compounds, and inorganic compounds as well as for the routine elemental analysis now commonly provided. Finally, it discusses the need for a well-designed quality assurance program and the role of such a program in providing data that are legally and scientifically defensible.		
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Future Trends in Environmental Monitoring and Instrumentation

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In the last three to five years there has been considerable advancement in our understanding of the space and time distribution of pollutants through our urban and nonurban areas, and great improvements have been realized in measurement methods. These favorable changes may serve as a technical foundation for a more analytical or quantitative approach to the design and planning of environmental monitoring systems. More and more we recognize that environmental quality monitoring is a very complex operation and requires a pollutant-specific systematic approach. Without an overall approach based upon stated objectives and guidelines, proper environmental quality assessment cannot be accomplished. Failure to recognize and to take into account the complexities involved has led to the present situation where we cannot document the relationship between sources and exposure or between exposure and effects.

If we are to aim environmental pollution control directly at relief from adverse effects of pollution, then we must have three kinds of essential information: 1) We must know the relationship between the pollutant exposure of the receptors at risk and the effects of the pollutants on these receptors; 2) We must know the total exposure levels to which the receptors are subjected and how these exposure levels are linked to the emissions from pollutant sources; 3) We must know how to control the pollutant sources so as to reduce total exposure of the receptors to an acceptable level. Once we have developed and put into use control programs that are based upon an exposure source-linked model, then we must have monitoring data that will determine compliance and also show if the control programs are achieving their intended purposes.

Major questions which must be considered in an environmental quality monitoring system are:

1. What are the objectives of a monitoring network?

2. What is the area for which the measurements are required?

3. What is the proper mix and location of movable, mobile and airborne stations? In what media should these stations be located, and what is the role of modeling in achieving the objectives?

4. What level or degree of error is acceptable?

5. What is the importance of exposure monitoring as related to the pollutants?

6. What related meteorological and hydrological data must be collected with the environmental quality data?

7. What quality assurance program is necessary to assure that the data are representative and legally and scientifically defensible?

8. What is the importance of sample averaging time to the network design?

9. What are the effects of physical transformations on the sampling location and network design?

Integrated approach

The goal of environmental assessment is to quantitatively describe and link the sources, transport mechanisms, chemical, physical and biological interactions, the major pathways of exposure, and the resulting effects of the pollutants on man and his welfare. The integrated exposure monitoring system simultaneously takes these things into account, that is, the critical receptor, critical transport pathways and the critical sources. The term "critical" designates the specific and important population at risk and the specific transport pathways leading from the important sources to this receptor population. While all sources and pathways are included, instead of general ambient environmental monitoring, special monitoring of the major pollutant chain is done specifically to permit control of the critical sources.

Biological monitoring

The monitoring of tissues and biological fluids collected from receptor plants, wildlife, domestic



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animals, and humans can indicate patterns, trends and levels of environmental pollutants or their metabolites. Valuable information on lead, cadmium, mercury and arsenic exposure may be furnished by the analysis of selected human tissues or fluids, such as hair, teeth, fingernails and blood.

Biological monitoring also can indicate potential long-term effects of low-level exposures of atmospheric pollutants on plants. For example, some research indicates that exposure of plants to low levels of air pollutants over long periods of time may result in smaller, less hardy plants, which could have a profound effect on world food supplies sometime in the future.

Personal exposure

Air monitoring systems currently in use are of limited value for measuring human exposure. A particular need exists in this area for a personal sampling device which would give a quantitative measurement of the concentration of pollutants at the breathing zone as an individual performs his daily activities. Such a device would integrate exposure in the breathing zone over a considerable period of time and through space. This information could be correlated with that obtained from sensors at fixed locations.

The availability of such personal monitors would make it possible: to determine personal exposure, to determine high-risk subpopulations, to calibrate fixed-station measurements, to validate and update models, to determine indoor exposure, and to determine exposure rapidly when new dangers from pollutants are discovered—such as from spills or large releases.

Quiet, acceptable small-scale instruments for personal monitoring are yet to be developed. Likewise, quiet indoor air monitors having desirable response characteristics, have yet to be marketed. However, progress in these areas can be expected with recent advancements in electronic miniaturization.

Respiratory irritants

A great deal of evidence shows that many chemicals exacerbate respiratory tract irritation and respiratory diseases, including sulfuric and nitric acids, aerosols, various types of organic acids and organic nitrogen compounds. Existing analytical technology can solve the problem of specific compound identification and measurement in ambient air. What is needed, though, is off-the-shelf analytical laboratory instruments for making the needed measurements of chemical compounds in conjunction with epidemiological studies.

Aeroallergens are airborne particles that are deposited in the upper air passages and cause severe adverse respiratory responses in large numbers of individuals. This acute type of environmental health problem exceeds all others in instance and

severity of repeated acute, albeit temporary, debilitation among susceptible individuals. The diversity of recognized aeroallergens imposes great limitations on monitoring efforts. The most difficult to monitor are airborne house dusts, mammalian danders, arthropod fragments and plant humus. Aeroallergens such as pollens and larger fungal spores are easily identified and quantified by light microscopy, but other types of aeroallergens must be recovered in culture and can pose problems related to viability of the sample and substrate selectivity.

One of the major problems in measuring aeroallergens is a lack of efficient differential samplers. Sampling devices including isokinetic impactors are needed especially for nonspherical particles and those of extreme size ranges. Despite the long-recognized problem with aeroallergens, we still lack systematic monitoring methods for collection and analysis. Perhaps some of the problem here is a lack of professional understanding about the use of aeroallergen data.

Air monitoring

There is still the need for both batch sampling and continuous sampling and analysis for general air pollutants. One of the present and future requirements for instruments is that they must be real-time, that is, they must have a one-second to 10-second response time. These instruments are needed for total sulfur, sulfuric acid, sulfur dioxide, hydrogen sulfide, nitric acid and ammonia.

Improved aerosol sampling methods—that are size selective—are required. The fine aerosols, less than two micrometers in diameter, should be separated from coarse aerosols. Airborne aerosol collection instruments need to measure only the fine particles, but ground-based stations should measure both fine and coarse particles.

Reliable gas chromatographs that can be operated successfully and with ease under conditions of variable pressure and temperature need to be developed. These systems must be able to be placed in medium to small aircraft for airborne measurements. Airborne gas chromatography technology is needed for atmospheric pollutants such as ammonia, reactive hydrocarbons, hydrogen sulfide, mercaptans, peroxyacetyl nitrate (PAN), and specific tracer gases. Such instrumentation also can be placed on tethered or constant-level balloons (tetroons), which may be useful, for example, in plume-scale experiments up to 100 to 200 kilometers and for applications to measure trajectories up to regional scale.

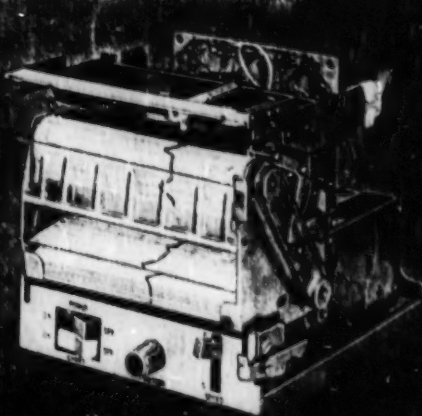
A very important type of instrumentation that is not yet perfected is that which measures visibility and transmissivity. What is needed is an instrument which can measure the impact of small particles and organic aerosols on visibility or transmissivity and which will be accepted as the standard or reference method by the various users. This

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type of instrument is critical for measuring significant deterioration in rural or nonurban areas.

Water monitoring

It is well-accepted that rising manpower costs justify increased emphasis on rapid methods of collecting monitored data in survey operations. At the same time, the need to reduce, analyze and report on these data will reduce the manpower available for field collection efforts.

A logical approach, even in the water monitoring area, is to turn increasingly to airborne methods. The ultimate approach, of course, is remote sensing. However, it is not now and probably never will be possible to measure all parameters of interest remotely. Therefore, it is necessary to utilize contact sensing and sample collection for subsequent laboratory analysis.

Air-droppable sensing and sampling systems are needed which would employ miniaturized systems including data microprocessors. These units should be capable of storing data and/or communicating with either fixed bases or the deploying aircraft and should be inexpensive enough that their loss can be tolerated by small budgeted programs. They should have fairly long lives—30 days or more—and have station-keeping ability.

Such instrumentation is within present state-of-the-art, except for cost and size considerations. Limnological sensor packages are available now which contain a submersible sensing unit and a deck readout connected by a cable. The sensor package has either digital or analog readout and possibly a jack for recording. Even this system is relatively bulky and lacks a "total systems" approach.

Another problem concerns translation devices and software. They are often considered proprietary, and data reduction must be carried out at the manufacturer's facility. This imposes severe constraints and demands on the typical researcher or control official who is faced with the task of maintaining the instrument for real-time use.

Similar types of instrumentation are needed for monitoring spills. A desirable instrument would be a single, lightweight, self-contained sensor package with an internal recorder, an operational life of up to 30 days, and high-operational efficiency and calibration characteristics. Such a boat- or air-droppable device also could have the ability to take physical water samples. This unit could be used for unattended monitoring with little probability of being vandalized.

Again the problem of multielement and multi-compound analysis is one to be considered. Laboratory analyses are still generally tedious and expensive. Further progress toward automation, simplification of sample preparation, and procedures for multielement and/or chemical analyses is required to reduce the time and cost of sample

analysis. Iterations between those who develop techniques for environmental measurement and those who assess health effects of environmental pollutants have increased the awareness that comprehensive chemical analysis must be applied to water. In most rivers and lakes most of the organic compounds are present at levels less than 10 parts per billion. To add to the chemist's nightmare, in most streams and lakes there are probably 10^4 or 10^5 organic compounds present, many of which are important with respect to assessing environmental health effects.

Remote sensing

Environmental remote monitoring is receiving increased emphasis as a part of the comprehensive monitoring program within EPA and various state and local agencies. Two obvious advantages of remote sensing are perspective and the potential for cost-effectiveness. In the future, we see the utilization of a large variety of remote sensing instrumentation for pollutant-specific monitoring and general survey purposes.

Examples of these instruments include ground-based instrumentation for quickly assessing the concentrations of atmospheric sources of pollution, that is, sulfur dioxide and nitrogen dioxide; instruments for ground-based measurements of local atmospheric plume dispersion and atmospheric inversion heights; those for measuring algal concentrations in water and for characterizing oil spills on water; instruments to measure organic content of lakes and rivers; and those needed for research studies such as long-range transport of oxidants.

Remote monitoring techniques also include photographic techniques for assessing the impact of land-use patterns on pollution in the air and water. Thermal scanners are presently used to measure the impact of hot water discharges on the receiving water. Multispectral scanners and Landsat satellite systems are presently being applied cost-effectively to establish land-use trends and relative water quality.

Laboratory support

Improved sampling techniques, lower limits of detection, and specificity are problems that have been referred to previously. Analytical chemistry has moved in the past decades from manual one-by-one sample processing to sophisticated automated techniques. There has been a lag in applying these methods to routine environmental monitoring, primarily because of the high cost associated with many of the methods as well as a lack of understanding of the methods and their limitations.

Organic compounds—One general analytical area that must be emphasized is compound as opposed to elemental analysis. Future requirements include trace organic analysis, oxidation state determina-

tion of various elements and compounds, chemical characterization of the various particulate size fractions and improved multielement analytical techniques. Presently, Fourier transform infrared spectroscopy can serve only as a confirmatory technique for both organic and inorganic materials at relatively high concentrations, as the detection limits are at about the microgram level. Only the gas chromatograph-mass spectrometer system can now achieve the necessary detection limits, but the procedure is slow and complex. Other current methods for trace organic analysis are thin layer chromatography-fluorometric analysis, gas chromatography with improved detectors such as microwave-excited emission for organometallics, and high-pressure liquid chromatography with ultraviolet absorption or fluorescent detectors. All of these methods currently need to be improved.

A newer technique for organic trace analysis in water is laser Raman spectroscopy. When detection limits are satisfactory, it will be a breakthrough in that it will omit the requirement for sample preparation. Fourier transform nuclear magnetic resonance (NMR) has increased the sensitivity of NMR techniques to the milligram level, but this detection level must be improved to microgram and picogram levels to be useful in the analysis of environmental samples.

Inorganic compounds—Fewer methods exist for the analysis of inorganic compounds. Determination of functional groups may be done by infrared techniques. Analysis for inorganic ions in solution may be carried out by laser Raman techniques or by newer specific ion electrodes. However, the important oxidation state information, which in some cases determines the toxicity of an element in various solid compounds, is difficult to obtain with present techniques. Electron spectroscopy for chemical analysis (ESCA) is the principal method of providing this information. Compounds containing iron and tin may also be investigated for oxidation states by Mossbauer spectroscopy. If the inorganic compound exists as a definite crystalline material, then micro-x-ray diffraction techniques may be used for qualitative and quantitative determinations.

Particulates—Respirable-sized particulate matter and its chemical characterization will be of continuing importance. Microprobe techniques including x-ray emission will therefore become more significant. ESCA and x-ray diffraction methods also will be of value to analyze these particulates.

Elemental analysis—In elemental analysis the older, highly specific spectroscopic techniques—absorption and emission—remain as the proven methods. New sources, detectors and data processing methods have improved the basic techniques. For cost-effectiveness, the multielement methods such as plasma-excited emission and energy-dispersive x-ray emission spectrometry will continue to be important. The advent of optical detectors

like the optical multichannel analyzers with multiplexed information acquisition will have a great impact on atomic absorption and emission analysis in the near future.

Quality assurance

Policy decisions concerning environmental quality must be based on valid and comparable measurements. In order to obtain legally and scientifically defensible data, a comprehensive quality assurance program is necessary to accompany any monitoring project. Substantial advances have been made in recent years in assuring the quality of environmental measurements, especially for the legally regulated substances in air and water. This was accomplished primarily through EPA-sponsored chemical and physical research programs, both in-house and at NBS and other public and private institutions.

There remain, however, a large number of substances and measurement processes in air, water, soil, food and occupational environments for which adequate standards are not yet available.

The quality assurance programs currently being conducted by the EPA include the distribution of reference samples and materials, the evaluation of methods, laboratory performance studies and the preparation of quality control guidelines, manuals and protocols.

New demands are being placed on our quality assurance programs as a result of the rapid expansions of the energy program, renewed and increasing interest in the naturally occurring radionuclides associated with nuclear fuel cycle and phosphate mining processing, the promulgation of drinking water regulations and the Toxic Substances Control Act, and the growing national concern with heavy metals, toxic elements and carcinogenic compounds in the environment.

In light of past experiences and current demands, there are a number of needs which must be cooperatively addressed by the public and private sector:

- the preparation of new reference materials
- clean-cut, well-defined procedures to establish traceability of measurements to the National Measurements System
- better guidelines on quality control procedures and calibration techniques for use with the field and laboratory instruments required to monitor radiation, pesticides, and toxic substances in air, water, biota and soil
- increased communication, liaison and cooperation between government agencies and equipment manufacturers
- training in calibration and use of both field and laboratory instruments.

GEORGE B. MORGAN is Acting Director of the EPA's Environmental Monitoring and Support Laboratory in Las Vegas, NV. Essay is based on his address presented at the 1976 ISA Conference in Houston.